


MOKELUMNE WATERSHED AVOIDED COST ANALYSIS:

Why Sierra Fuel Treatments Make Economic Sense

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Appendix G: North Fork Mokelumne River Sediment Budget Analysis

G.1 Introduction

A key part of this analysis is an assessment of the relative importance of sediment sources that have already contributed to the filling of existing water and energy impoundments, specifically the PG&E Tiger Creek Afterbay. One sediment source is from mass wasting (landslides), which was discussed in the previous chapter in the context of possible future events. However, a number of landslides are apparent on aerial imagery in the project area and other smaller landslides (too small to be visible on aerial imagery) are documented in the area. The visible landslides are nearly all in the canyon of the North Fork Mokelumne, on the north side of the river near PG&E hydropower infrastructure (canals, pipelines, and holding ponds). Exact causes of these landslides are not documented but one possible cause or contributing factor could be water leaking from the hydropower infrastructure. Site-specific documentation regarding smaller landslides is available, which are usually associated with a specific project or road maintenance need. While large landslides visible on aerial imagery have been mapped, there has not been a comprehensive landslide inventory, including small landslides across the project area.

Photo evidence of landsliding is sparse, although this appears to be the result of the difficulty in capturing the relatively small scale of landsliding (compared to the Klamath Mountains or Coast Ranges) rather than a lack of landsliding. This is supported by the fact that field inventory has identified specific landslides although these identified landslides are too small to be readily identified on orthophotos.

An accurate inventory of landsliding in the project area would take many weeks of field inventory. Photo inventory alone would miss too many landslides, especially road cut and fill slides, which probably make up the majority of landslide sedimentation in the project area. Instead we modeled landsliding based on geologic type and disturbance history and come up with a reasonable estimate of landsliding. We also factored in future wildfire based burn severity mapping. We did not devote time to mining effects as, to our knowledge, it has not been demonstrated that mining has had a significant impact on sedimentation in the project area.

G.2 Methodology and Data Used in Analysis

G.2.1 Datasets

<u>NHD</u> – National Hydrologic Dataset for the Mokelumne River sub-basin includes streams and lakes as well as man-made features such as reservoirs and pipelines.

<u>WBD_HU10</u> – Watershed Boundary Dataset, 10 digit (5th field) Hydrologic Units (watersheds). The North Fork Mokelumne River consists of two 5th field units, Upper North Fork Mokelumne River (HU code 1804001201) and Lower North Fork Mokelumne River (HU code 1804001204).

The split between Upper and Lower is at the confluence of North Fork Mokelumne River and Cole Creek, about 3 kilometers downstream of Salt Springs Reservoir, with Cole Creek considered in the Upper North Fork Mokelumne River watershed.

WBD_HU12 – Watershed Boundary Dataset, 12 digit (6th field) Hydrologic Units (sub-watersheds).

Project Boundary – The project boundary for this project was created using WBD_HU12. As the intent of the project is to determine a coarse sediment budget in the North Fork Mokelumne River watershed between Salt Springs Reservoir and Tiger Creek Afterbay, the entire North Fork Mokelumne River was not analyzed. Sixth field sub-watershed boundaries were used with the following exceptions. Watershed lines were drawn at the dam for Salt Springs Reservoir (to exclude the portion above the dam), at the dam for the Lower Bear River Reservoir (to exclude the portion above the dam), and at the dam for Tiger Creek Afterbay (to exclude the portion below the dam) to create a project boundary. The sub-watersheds in the project are as follows (See Table G.1).

Table G.1: Subwatersheds and acreage

Sub-watershed	*Sub-watershed Name*	*Project Hectares*	*Total Sub-watershed Hectares*
180400120105	Cole Creek	6,086	6,086
180400120106	Salt Springs Reservoir-North Fork Mokelumne River	648	11,325
180400120401	Bear River	3,968	13,629
180400120402	Blue Creek	7,504	7,504
180400120403	Panther Creek	4,852	4,852
180400120404	Tiger Creek-North Fork Mokelumne River	12,616	12,616
180400120405	Mill Creek-North Fork Mokelumne River	3,287	7,346
	Total Project Hectares	*38,961*	

Table G.2: Ownership for the project area and total acreage:

Owner/Manager	*Hectares*
Eldorado National Forest	13,473
Stanislaus National Forest	8,512
Bureau of Land Management	274
Private Land	16,702
Total Project Area	*38,961*

Roads – The roads for the project area have been pulled from the roads layers from the Eldorado and Stanislaus National Forests, with some additional roads added if readily visible on aerial imagery but not in either layer. A number of roads in the far western portion of the project area, in what appears to be a residential subdivision, have not yet been mapped. Most roads within the clip boundary had been attributed with "system" (county road, National Forest System Road, etc.), surface type, and lanes (indicator of road width). Unattributed roads I called Forest non-system or private (depending of land ownership) with single lane and native surface.

Table G.3: Road mileage summary for the project area

System	*Surface Type*	*Lanes*	*Miles*
State Highway	AC - ASPHALT	2 - DOUBLE LANE	15.2
County Road	AC - ASPHALT	2 - DOUBLE LANE	2.2
County Road	AGG - CRUSHED AGGREGATE OR GRAVEL	1 - SINGLE LANE	0.5
County Road	NAT - NATIVE MATERIAL	1 - SINGLE LANE	0.4
National Forest System Road	AC - ASPHALT	2 - DOUBLE LANE	1.7
National Forest System Road	AC - ASPHALT	1 - SINGLE LANE	4.4
National Forest System Road	BST - BITUMINOUS SURFACE TREATMENT	2 - DOUBLE LANE	8.6
National Forest System Road	BST - BITUMINOUS SURFACE TREATMENT	1 - SINGLE LANE	41.1
National Forest System Road	AGG - CRUSHED AGGREGATE OR GRAVEL	1 - SINGLE LANE	45.9
National Forest System Road	IMP - IMPROVED NATIVE MATERIAL	1 - SINGLE LANE	1.1
National Forest System Road	NAT - NATIVE MATERIAL	1 - SINGLE LANE	255.4
Forest Non-System Road	NAT - NATIVE MATERIAL	1 - SINGLE LANE	21.4
Private Road	AC - ASPHALT	1 - SINGLE LANE	0.1
Private Road	AGG - CRUSHED AGGREGATE OR GRAVEL	1 - SINGLE LANE	1.3
Private Road	NAT - NATIVE MATERIAL	1 - SINGLE LANE	228.5

Burn Severity and Fire History – These layers help show erosion-accelerating disturbances in the watershed. Fire history is not particularly useful since there is no indication of severity as there is in the burn severity layer; however burn severity layers only date from 1991 and younger.

Units – Timber harvest units on National Forest lands from the FACTS database, although we have included only land disturbing activities, not other activities tracked in the database such as stand inventories.

Timber Harvest Plans – State managed logging activity data on private land. Includes separate feature classes for Amador and Calaveras counties.

Digital Elevation Model – Grid of elevations, from which can be derived slope classes, contours, and hillshade.

Rainfall_Rantz – Average rainfall.

Aerial Imagery – Many tiles of rectified aerial imagery (orthophotos), pulled from public access internet sites, mostly dating around 2010.

Soils_geo_group – This is a feature class compiled from the best available bedrock mapping and Order 2 soil surveys. Individually, the three Order 2 soil surveys and the bedrock mapping do not cover the entire project area, and the soil surveys (three of them) across the area do not cover the entire project area. The bedrock mapping and soil surveys were combined to make one feature class that covered the project area. . This feature class includes the original map unit symbols and map unit names from the soil surveys, the geologic groups from the bedrock mapping, and the attribute soils_geo_group with surface texture and percent fines interpretations for each group. The soils_geo_group, with interpretations, are as follows (See Appendix C: C.3.2.4).

Table G.4: Soil Layer Descriptions

Soils Geo Group	*Percent Fines*	*Surface Texture*
Deep to moderately deep soils, granitic	30%	coarse sandy loam
Glacial deposits, mostly granitic	30%	coarse sandy loam
Rock outcrop with deep pockets of soil, mostly granitic	30%	coarse sandy loam
Rock outcrop, mostly granitic	30%	coarse sandy loam
Shallow to moderately deep soils, volcanic	40%	cobbly sandy loam
Deep to moderately deep soils, volcanic	40%	gravelly sandy loam
Marshy ground, mostly granitic	40%	sandy loam
Shallow to moderately deep soils, metamorphic	50%	gravelly loam
Deep soils, metamorphic	60%	loam

G.3 Methods

Order 2 soil mapping is of higher resolution than bedrock mapping, so soil mapping lines are used instead of bedrock lines for the soils_geo_group. In cases where soil surveys are not edge matched correctly, or soil survey information is not available, the bedrock interpretation was used to determine soils_geo_group value. Rock outcrop, glacial deposits, and marshy ground could occur on any bedrock type, and the soil survey information does not specify bedrock type for these geologic groups. The majorities of these types are in granitic bedrock and acquires a granitic interpretation for soil texture and percent fines.

There are three basic rock types in the project area: granitic, volcanic, and metamorphic. Granitic rocks are those of the Sierra Nevada batholith, mostly granodiorite or diorite. When exposed as rock outcrop these are nearly impervious to landsliding and erosion, except for rock falls and small amounts of sheet erosion as individual grains weather and wash from exposed bedrock. But once weathered to soil, erosion can occur readily, especially after disturbance, because of coarse textured soils with low percentages of binding fine material. Volcanic rock types are primarily andesitic mudflow deposits often identified as the Mehrten formation. The Mehrten formation is generally identified as the most landslide-prone group of rocks in the Sierra Nevada area. Even when exposed as rock outcrop, the andesitic mudflow deposits are generally weak and fractured and subject to landsliding. The metamorphic rocks include metasediments and metavolcanics of the

Northern Sierra terrane, generally the most weathered but least erosion-prone of the bedrock types.

Interpretations were made for percent_fines for each soils_geo_group based on dominant surface texture and bedrock type for each soil map unit. This interpretation is designed to allow estimation of eroded material that would likely be trapped in a reservoir. The majority of finer material, less than 63 microns, would likely wash through a reservoir while the majority of coarser material, greater than 63 microns, would likely be held in a reservoir and contribute to reservoir filling.

G.4 Results

A model estimating sediment delivery to streams from mass wasting was modified for the project area. This model has its empirical base in the Salmon Sub-basin Sediment Analysis [de la Fuente & Haessig, 1994] and uses methodology developed in Amaranthus et al. [1985], the Grider EIS [USFS, 1989] and KNF LRMP [USFS, 1995]. The model estimates sediment delivery using a matrix of coefficients (see Table G.5 below). Sediment delivery coefficients derived for this analysis are based on the Klamath Mountains work, although there is not much consistency between the North Fork Mokelumne project area and the Klamath Mountains. For one thing, landsliding rates are much higher in the Klamath Mountains than the Sierra Nevada. Table G.1 displays values to correlate mapped geology and soils types for the project area with mass wasting rates from the Klamath Mountains. End-result total sediment production estimates will be high compared to actual sediment production, but relative mass production between background, roads, and other disturbance (wildfire and timber harvest) should be realistic.

The project area for this analysis consists of the watershed area draining to Tiger Creek Afterbay, excluding the areas above Salt Springs Reservoir and Lower Bear River Reservoir. Total project area is 96,276 acres. Geology and soils types are mapped for the project area, as are roads and other disturbances. Roads and other disturbances are intersected with geology in GIS and acreages of each type of intersection is computed and multiplied by the factors in Table G.5 to arrive at the estimated mass wasting values displayed in Table G.6.

Table G.5: Estimated sediment delivery in m³/hectare/decade

Geology Type Description	*Slope Class*	*Background (estimate assuming area is undisturbed)*	*Roads*	*High impact fire or harvest[1]*	*Moderate impact fire or harvest[2]*
deep soils, metamorphic	<40%	0.5	34	3.9	2.2
deep soils, metamorphic	>40%	2.3	154.9	4.7	3.5
deep to moderately deep soils, granitic	<40%	1	66.1	10.4	5.7
deep to moderately deep soils, granitic	>40%	1.9	1105.2	19.6	10.7
deep to moderately deep soils, volcanic	<40%	2.3	154.9	4.7	3.5
deep to moderately deep soils, volcanic	>40%	3.6	292.8	11.2	7.4
glacial deposits, mostly granitic	<40%	1	66.1	10.4	5.7
glacial deposits, mostly granitic	>40%	4.1	12.1	10.4	7.3
marshy ground, mostly granitic	<40%	1	66.1	10.4	5.7
marshy ground, mostly granitic	>40%	4.1	12.1	10.4	7.3
rock outcrop with deep pockets of soil, mostly granitic	<40%	0.1	0.9	0.5	0.3
rock outcrop with deep pockets of soil, mostly granitic	>40%	1	66.1	10.4	5.7
rock outcrop, mostly granitic	<40%	0	0.2	0.1	0.1
rock outcrop, mostly granitic	>40%	0.1	0.9	0.5	0.3
shallow to moderately deep soils, metamorphic	<40%	0.1	0.9	0.5	0.3
shallow to moderately deep soils, metamorphic	>40%	0.5	34	3.9	2.2
shallow to moderately deep soils, volcanic	<40%	0.5	34	3.9	2.2
shallow to moderately deep soils, volcanic	>40%	2.3	154.9	4.7	3.5

[1] Includes clear cuts and other equivalent silvicultural prescriptions and wildfire resulting in canopy removal of 80 percent or more.

[2] Includes partial cuts and wildfire resulting in canopy removal of between 30 and 80 percent.

Table G.6: Estimated Sediment Delivery for the North Fork Mokelumne River

Background	*Additional from Roads*	*Additional from Harvest and Wildfire pre-2002*	*Total 2002*	*Additional from Wildfire and Harvest post-2007*	*Total 2007*
51,272	54,859	12,337	118,468	29,097	147,565

Predicted sedimentation volumes are in cubic meters that may be generated in a flood event with recurrence interval of 10-20 years. “Background” is the expectation if the project area is undeveloped, without roads, wildfire, or harvest units.

Time frames of 2002 and 2007 are selected for this analysis to demonstrate the impacts of the Power Fire of 2004 and other wildfires that occurred in 2002 and 2003. The 2007 year is used as the post-wildfire output because salvage harvest operations from the Power Fire were still ongoing in 2006. As displayed in Table 6, the Power Fire, along with other wildfires and salvage operations during that time period, is expected to increase mass wasting sedimentation considerably, though not nearly as much as the chronic conditions that results from the extensive road network within the project area.

Other Considerations – Forest data concerning mining activity was not obtained, but there appears to be (based on review of orthophotos) very little stream sedimentation that has occurred in the project area as a result of mining.

G.5 Tiger Creek Afterbay

Tiger Creek Afterbay capacity at the time it was built (1931) was 4,884,588 cubic meters (3960 acre-feet), based on the info historical data. A bathymetric survey of the Afterbay was performed in the fall of 2013 (Appendix F), resulting in an estimated 2013 capacity of 1,158,974 cubic meters (940 acre-feet). Therefore, the amount of sediment deposition over 82 years, not including an unknown quantity of sediment flushed through the Afterbay dam, is 3,725,614 cubic meters (3020 acre-feet). In this analysis, we estimate an average non-fire (background + road erosion) mass-wasting sediment production of about 106,069 cubic meters (86 acre-feet) per year. For the North Fork Mokelumne study area of 38,978 ha, this is equivalent to a sediment yield of 2.72 cubic meters per hectare per year, or about 4 Mg/ha/yr. As previously noted, this estimate is on the high side because it uses coefficients developed for the more erodible Klamath terrain. Using our average of 106,069 cubic meters per year, it would take only 35 years for the Afterbay to collect the amount of sediment deposited in it, rather than the actual 82 years it took. This confirms that the average non-fire sediment production rate from the sediment budget report is higher than actual sediment production (assuming that sediment flushing is small relative to total deposition), although not out of the range of observed sediment production rates in the Sierra Nevada. As noted in this chapter, the relative importance of background, roads, fire, and harvest-related erosion is more reliable and relevant to management decisions than the magnitude of the estimates.

References:

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Disclaimer

This report is rich in data and analyses and may help support planning processes in the watershed. The data and analyses were primarily funded with public resources and are therefore available for others to use with appropriate referencing of the sources. This analysis is not intended to be a planning document.

The report includes a section on cultural heritage to acknowledge the inherent value of these resources, while also recognizing the difficulty of placing a monetary value on them. This work honors the value of Native American cultural or sacred sites, or disassociated collected or archived artifacts. This work does not intend to cause direct or indirect disturbance to any cultural resources.

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